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Article

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Novel circuit to compensate the effect of source open circuit fault in distributed generation system

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Abstract

In this paper a novel compensating circuit, composed of capacitors, one IGBT switch, and a diode bridge is designed and employed within a SOFC distributed generation system connected to a micro-grid. The DG system consists of the FC stack, a Cuk converter, a three phase inverter, the proposed compensating circuit, and Type 2 Fuzzy logic controller to adjust the output voltage to its reference value, to manage the charging of the compensating circuit capacitors during normal operation, and to manage the discharge of the compensating circuit during fault to ensure the continuous power supply to the load during the open circuit fault of the SOFC. A detailed description of the managing controllers and switching sequences is also given. Results proved the validity of the compensating circuit in supplying the load during the absence of the main source, hence preventing serious consequences of shutting down important loads.

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Keywords: Compensating circuit; Type 2 fuzzy logic controller; Cuk converter; Grid

1. Introduction

Fuel Cells are applied in stationary and mobile power generation and are connected to distribution grid. The distributed generation (DG) is defined by the Electric Power Research Institute (EPRI) as a small scale (0–50 MW) energy resource connected directly to the distribution network [1–4].

In this paper a novel compensating circuit, composed of capacitors, one IGBT switch, and a diode bridge is designed and employed within a SOFC distributed generation system connected to a micro-grid. The operation of the whole FC-compensating circuit-DG system is investigated during the interruption of power generation from the SOFC. The steady state currents and voltage profiles at three points of connection within the generation system during normal operation are presented. The currents and voltages at these points during the supply interruption are then presented, with connection of the proposed compensating circuit. Results proved the continuous supply

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Nomenclature

E_{nernst}	Open circuit Voltage;
P_{H_2}	Partial pressure of hydrogen and oxygen, [atm];
P_{O_2}	Partial pressure of oxygen, [atm];
T	Refers to FC operation temperature, [°K];
V_{act}	Activation voltage drops in FC electrodes
V_{con}	Voltage drop corresponding to mass transport
V_{ohmic}	Ohmic voltage drop due to resistive losses in the cell

of power to the load, preventing shut-down of critical loads. The THD at these points are also investigated before and after the open circuit fault. Fuzzy control is applied to manage the DG system operation to ensure continuous supply of power to the microgrid.

2. The distributed generation system description

Fig. 1 shows the block diagram of the proposed distributed generation system composed of a SOFC, a Cuk converter, a VSI PWM inverter and the proposed compensating circuit

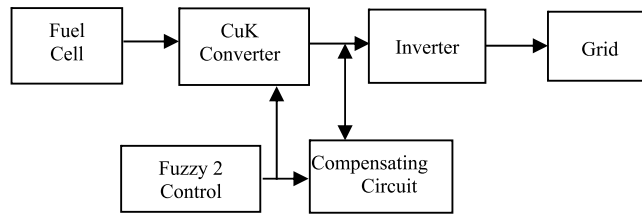


Fig. 1. Block diagram.

The CuK converter adjusts the dc output of the SOFC, applies it to the PWM inverter with constant dc voltage to be supplied to the grid with constant frequency. The switch SW_1 connects the fuel cell output, in the case of normal operation, while the switch SW_2 at the output of the compensating circuit allows charging the circuit capacitors. The operation of the converter, inverter and switches is adjusted by Fuzzy logic 2.

2.1. The SOFC model

FC converts chemical energy to electrical energy. The amount of output voltage in each cell is small. Therefore, cells are connected in series to gain a higher output voltage. FC output voltage is given as [5]:

$$V_{\text{FC}} = E_{\text{nernst}} - V_{\text{act}} - V_{\text{ohmic}} - V_{\text{con}} \quad (1)$$

where: E_{nernst} is the open circuit voltage defined as follows:

$$E_{\text{nernst}} = 1.229 - 0.85 * 10^{-3}(T - 298.15) + 4.3085 * 10^{-5}T [\ln(P_{\text{H}_2}) + 0.5 \ln(P_{\text{O}_2})] \quad (2)$$

2.2. DC/DC converter with type 2 fuzzy control

The dc output voltage of the CuK converter is greater than its dc input voltage. The switch SW_1 is controlled with T2-FLC to produce constant dc voltage to supply the inverter connected to the ac microgrid.

2.3. PWM inverter

The simplified circuit diagram for a three-phase, two-level, IGBT voltage source converter (VSC) is illustrated in Fig. 2. The Flat Top PWM is used for switching the IGBTs. The inverter switches are controlled with T2-FLC to apply ac voltage with constant frequency to the microgrid.

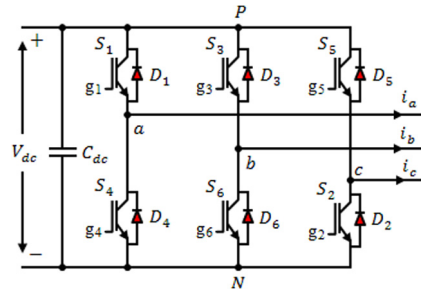


Fig. 2. Phase PWM inverter.

2.4. The compensating circuit

Fig. 3 shows the proposed compensating circuit for mitigating the effect of open circuited FC, or loss of supply. The circuit comprises three capacitors (C_f , C_{f1} , and C_d), two pulse diode rectifier-bridge, and a small smoothing reactor (L) with additional tuning resistor (R). The filter-compensator capacitors are charged via the FC during normal operation. If an open circuit fault takes place, i.e. the fuel cell fails to supply the load; the switch SW_2 of the compensating circuit supplies the AC microgrid with constant voltage, [6].



Fig. 3. The proposed compensating circuit.

2.5. The control technique

The control of dc CuK converter, the inverter supplying the load, and the compensating circuit operation is executed using type 2 Fuzzy logic control technique. The major structure difference between type 1 and type 2 FLC is that the defuzzifier block of a type-1 FLS is replaced by the output processing block in a type-2 FLS which consists of type-reduction followed by defuzzification block. T2-FLC, can be used when the circumstances are uncertain to determine exact membership grades such as when the training data is affected by noise. T2-FLC reaches steady state value faster than type-1 FLC, [7]. The control circuit depends on the magnitude of the output voltage of the dc converter. The control circuit controls the 2 switches SW_1 and SW_2 . When a change in the voltage occurs, the controller operates SW_2 instead of SW_1 to compensate the voltage drop.

3. Simulation results

The steady state voltage and current of the FC are given on Fig. 4. An open circuit fault is assumed from 0.65 s till 0.7 s, i.e. the SOFC fails to supply the load. The converter output voltage during the fault is shown in Fig. 5(a). It shows that the proposed FACT circuit compensates the voltage drop to supply the inverter. Fig. 5(b) demonstrates the FACT circuit current, showing the reversal of the current during the fault, due to the operation of SW_2 instead of SW_1 .

Fig. 6 proves that the voltage and current of the inverter is not affected by the open circuit fault due to the operation of the FACT circuit.

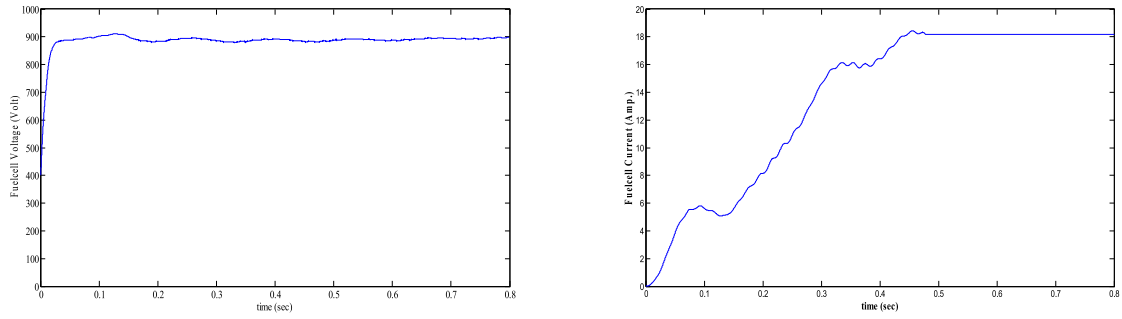


Fig. 4. SOFC voltage and current at normal operation.

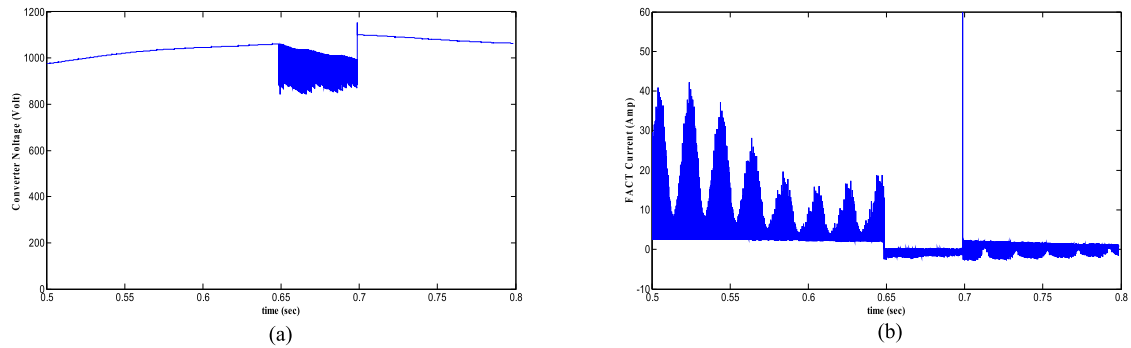


Fig. 5. (a) Output converter voltage during the fault, (b) The current of FACT during fault.

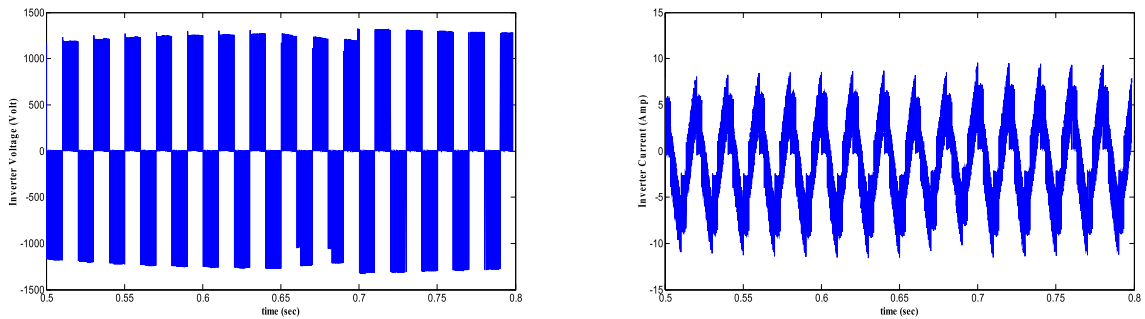


Fig. 6. Output voltage and current of the inverter.

Analyzing the THD of the inverter voltage during normal operation and with fault occurrence, as shown in Fig. 7(a) and (b), it is shown that during normal operation THD is 30.93%, while due to fault occurrence it became 31.26%. This is an incremental change due to capacitors of the compensating (FACT) circuit. While, the THD of the inverter output current increased from 21.36% during normal operation to 22.35% due to the open circuit fault as shown in Fig. 8(a) and (b). This is an incremental increase.

4. Conclusion

A compensating circuit, acting as a FACT device, is designed to provide continuous supply of load demand in a distributed generation system fed by a solid oxide fuel cell. The DG system consists of the FC stack, a CuK converter, a three phase inverter, the proposed compensating circuit, and Type 2 Fuzzy logic controller to adjust the output voltage to its reference value, to manage the charging of the compensating circuit capacitors during normal operation, and to manage the discharge of the compensating circuit during fault to ensure the continuous power

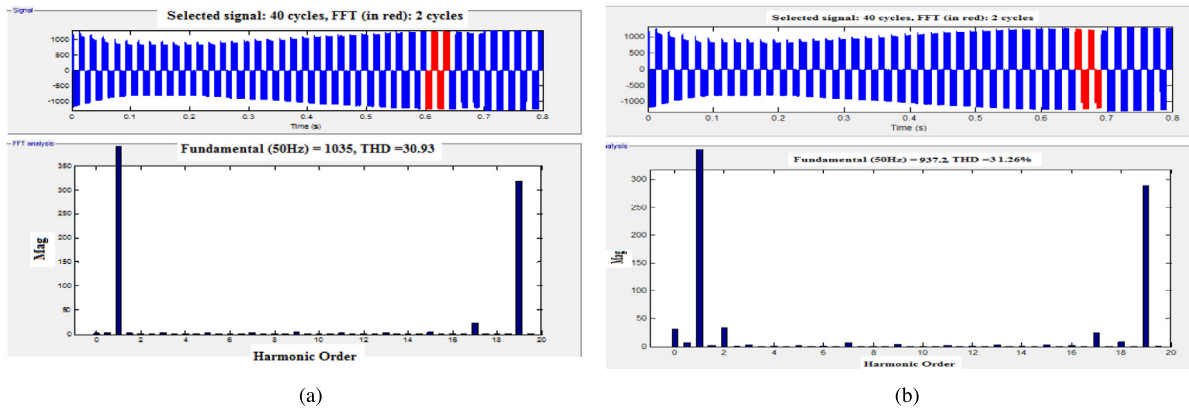


Fig. 7. The THD voltage of inverter (a) at normal operation and (b) at fault.

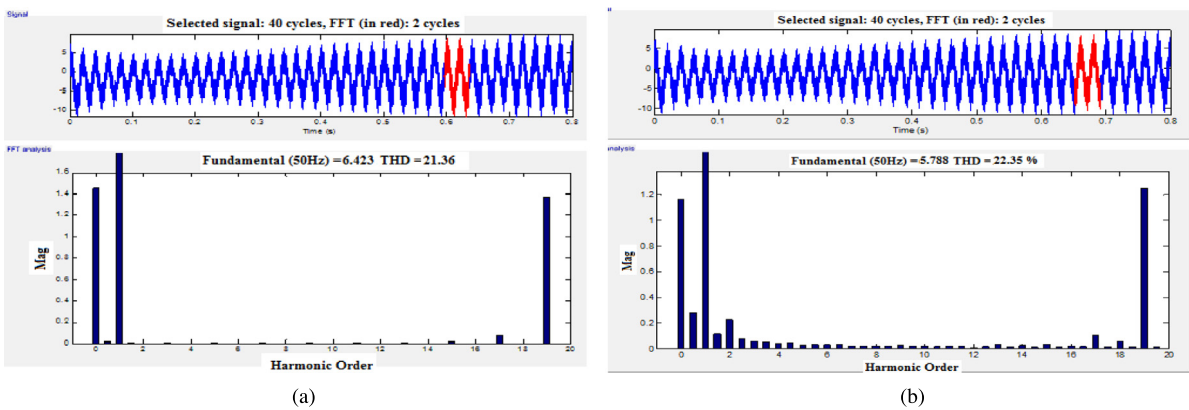


Fig. 8. The THD current of inverter (a) at normal operation and (b) at fault.

supply to the load during the open circuit fault of the SOFC. The DG system consists of the FC stack, a CuK converter, a three phase inverter, the proposed compensating circuit, and Type 2 Fuzzy logic controller to adjust the output voltage to its reference value, to manage the charging of the compensating circuit capacitors during normal operation, and to manage the discharge of the compensating circuit during fault to ensure the continuous power supply to the load during the open circuit fault of the SOFC. Results proved the continuous supply of the load demand during open circuit fault with an incremental increase in the THD of the inverter output voltage and current, proving the efficiency of the proposed circuit.

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